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USE OF La^{140} AS RADIOTRACER IN (PRE-BUGGY) CHEMICAL EXPLOSIONS

Preparation and Determination of Its Reaction with Environmental Materials

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ADMINISTRATIVE INFORMATION

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ABSTRACT

The pre-Buggy experiment conducted by the U. S. Army Engineer Nuclear Cratering Group was designed to measure the fraction of vented radioactivity from a series of HE underground detonations containing radioactive sources.

NRDL assisted in this experiment by preparing 29 capsules containing curie amounts of La^{140} for shipment to the Nevada Test Site (NTS) on schedule. The level of gamma activity in each capsule was sufficient to provide a radiotracing of the debris which resulted from the detonation.

In addition NRDL furnished "always open" fallout collectors to sample the debris, and a low-geometry scintillation counter to measure its La^{140} content.

Particle size measurements of the debris indicated that La^{140} was adsorbed on the surface of the soil particles. Some 96 % of the activity was associated with sub-sieve particles representing only 8 % of the mass and 90 % of the available surface area.

SUMMARY

Problem

To assist the Nuclear Cratering Group in the Pre-Buggy experiment involving a series of La^{140} traced HE detonations at NTS. NRDL agreed to furnish the La^{140} required for radiotracing the debris from the HE detonations, 350 fallout collectors, and a low-geometry gamma scintillation counter.

Findings

The NRDL facilities at Camp Parks were adequate for sample preparation. Capsules with the proper activity were furnished as required by the Pre-Buggy firing schedule. The collectors and scintillation counter were satisfactory for collecting and measuring the debris from the radiotraced HE detonations.

INTRODUCTION

OBJECTIVE

The general objective was to assist the U. S. Army Engineer Nuclear Cratering Group (NGC) in the pre-Buggy chemical explosive experiment.

Specifically, NRDL accepted the responsibility for loading 21 capsules with curie amounts of La^{140} which were used to radiotrace the debris from the chemical explosive detonations and for preparing calibration sources to correlate different radiation measurements.

BACKGROUND

The Plowshare program is concerned with the development of peaceful uses of nuclear energy such as building dams, excavating harbors, and digging canals. Project Buggy is planned to investigate the feasibility of the latter by simultaneously detonating five nuclear charges to simulate the excavation of a canal with nuclear explosives. To obtain design data for the nuclear experiments, a pre-Buggy experiment with traced chemical explosives was conducted.

The main purpose of the pre-Buggy experiment was to determine the fraction of vented radioactivity from the explosion as a function of scaled depth of burst and charge spacing of a row of charges, and to refine existing data on crater size as a function of these parameters.

The pre-Buggy experiment consisted of a series of cratering detonations using 1,000 lb, spherical charges of nitromethane containing a radioactive tracer. Six single charges and four rows of five charges each, were detonated. The single charges were traced with about 20 curies, and each of the row charges with about 5 curies, of the gamma-emitting radionuclide La^{140}.

APPROACH

The choice of La^{140} as the radiotracer and methods of measuring the fraction of vented activity were discussed by NRDL personnel and members of the Nuclear Cratering Group. NRDL accepted responsibility for providing the radiotracer and loading the LRL-provided magnesium capsules with La^{140} precipitated as LaF_3. It was agreed that the total capsule activity could be best measured at NTS just prior to shot time. There was no particular requirement for the single charge detonations to have an exact curie content as long as there was sufficient activity to give good counting statistics. However, it was desirable to have about the same activity in each of the five charges in a given row.

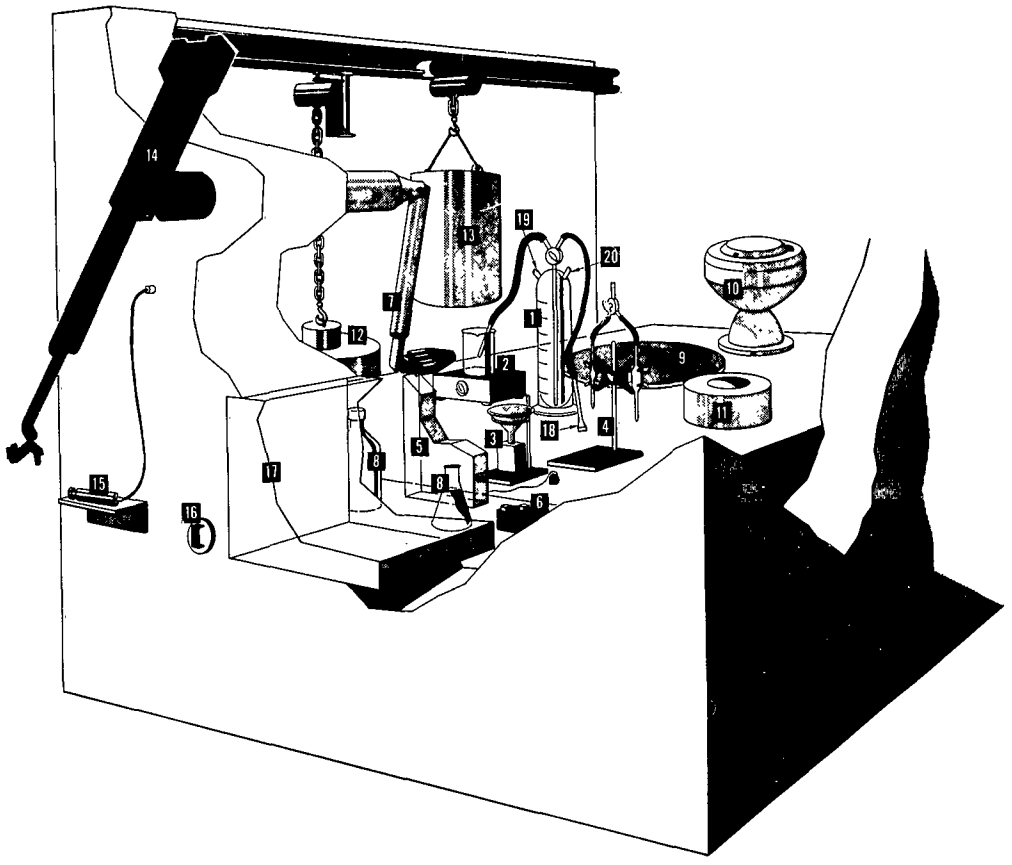
NRDL furnished 350 "always open" fallout collectors, and a low-geometry gamma scintillation counter for analytical measurements at the Nevada Test Site. An analytical balance and a nest of Tyler sieves were also sent to NTS so that mass distribution and activity distribution as a function of particle size could be measured. Some samples of the debris were returned to Camp Parks for wet sieving, leaching and exchange studies.

The Nuclear Cratering Group furnished magnesium capsules of their own design along with the jigs necessary to support the capsules and to screw on the cap. They also provided two shielded shipping containers for transporting the capsules to the Nevada Test Site.

EXPERIMENTAL PROCEDURES

HOT CELL AND HANDLING FACILITIES

The capsules were prepared in the NRDL hot-cell facility at Camp Parks, near Livermore, California. The hot cell, enclosing an area 8 ft by 8 ft, is constructed of concrete blocks which form a U-shaped shield, 2 ft thick. The cell is fitted with a zinc bromide-filled viewing window and a pair of Model 8 master-slave manipulators. Ventilation is provided by blowers which maintain a negative pressure inside the cell. The leakage air, amounting to $\sim$500 cfm, is exhausted through an absolute filter. A schematic arrangement is shown in Fig. 1



1. Graduate cylinder. 2. Hot plate and beaker. 3. Capsule loader. 4. Pipettes. 5. Lead glass shadow shield. 6. Centrifuge tubes. 7. Slave manipulator. 8. Reagents. 9. Waste disposal. 10. Centrifuge. 11. Lead shield. 12. Lead storage container. 13. Transportation container. 14. Master manipulator. 15. Remote pipette. 16. Access hole. 17. Zinc bromide window. 18. Fritted filter. 19. Water. 20. Pressure and vacuum.

Fig. 1 Hot Cell

Since the concrete wall and zinc bromide window provided insufficient shielding for the several hundred curies of radioisotopes which were required for the pre-Buggy capsules, a high-density lead glass window 12 in. by 8 in. by 2 in. thick was used inside the cell for additional shadow shielding. The window was mounted so that it could be moved by the manipulators to a position in front of the most concentrated activity.

A 1-1/2 in. diameter access hole through the face of the cell provided a convenient means of assaying capsule activities in situ.

ISOTOPE PROCUREMENT

Quarterly shipments of 2000 curies of Ba^{140} were obtained from Los Alamos Scientific Laboratory (IASL). This material, which is excess to the needs of IASL, is packaged at Los Alamos, trucked to Kirtland AFB, flown to Alameda NAS, and trucked to Camp Parks. The shipment was stored in the 9-in. lead storage container inside the hot cell shown in Fig. 1.

CAPSULE PREPARATION

La^{140} was separated from an equilibrium mixture by precipitating Ba^{140} as barium nitrate. The acid supernate containing the La^{140} was filtered off and evaporated to dryness. The La^{140} was taken up in water, precipitated as LaF_3, and placed in a magnesium capsule. The detailed procedure is described below.

Lanthanum Separation

An aliquot of the Ba^{140}-La^{140} solution was measured in the NRDL 4-pi ionization chamber to determine the volume necessary for the daily requirement.

La^{140} was separated from Ba^{140} in the apparatus shown in Fig. 1. At the start of the operation, a beaker on the hot plate containing 2

grams of barium nitrate, 0.1 gram of lanthanum nitrate, and the required Ba^{140}-La^{140} activity in about 100 ml of 0.1 N nitric acid. The solution was boiled until its volume was reduced to about 25 ml. Barium nitrate was then precipitated by adding 100 ml of concentrated nitric acid. The acid supernate containing the lanthanum was drawn through a fritted filter into a graduated cylinder, where the volume was adjusted to 300 ml with distilled water. An aliquot of the solution was measured in the USNRDL 4-pi gamma ionization chamber to verify the previous assay. The aliquot was retained for decay measurements and gamma spectra to determine the radiochemical purity of the La^{140}.

Lanthanum Fluoride Precipitation

The radioactive lanthanum fluoride was prepared in 40-ml centrifuge tubes. Precise volumes were measured by rigidly mounted pipettes. Solutions required inside the hot cell were:

(1) 0.1 N-HNO_3
(2) Inactive lanthanum nitrate, (1 g $La(NO_3)_3 \cdot 6H_2O$/ml)
(3) Potassium fluoride, (1 g KF/ml)

The acid solution containing the La^{140} was transferred from the graduated cylinder to a clean beaker on the hot plate and evaporated to dryness. The dry lanthanum nitrate was taken up in 0.1 N nitric acid: 25 ml was used for a single-charge capsule, and 125 ml was used for 5 capsules destined for the row charges.

Five ml of inactive lanthanum nitrate solution, 25 ml of the radioactive solution, and 5 ml of the potassium fluoride solution were pipetted in that order into one 40-ml centrifuge tube(or 5 tubes for the row-charge capsules). The tube(s) was centrifuged for 10 min and the supernate decanted into a waste beaker.

The lanthanum fluoride precipitate was dried in the centrifuge tube on the hot plate, and transferred to the magnesium capsule as shown in Fig. 2. Some scraping with a spatula and brushing was necessary to ensure a quantitative recovery.

A 30-ft string was tied to the capsule cap and marked with ink at 5, 10, and 20 ft from the capsule end to facilitate handling at NTS. The string was coiled and placed in a plastic bag so that only the cap and 1 ft of string was unprotected from contamination inside the cell. The cap and string were pushed through the access hole and picked up with the manipulators inside the cell. The cap was screwed on with the manipulator and securely tightened down with a jig which provided additional leverage.

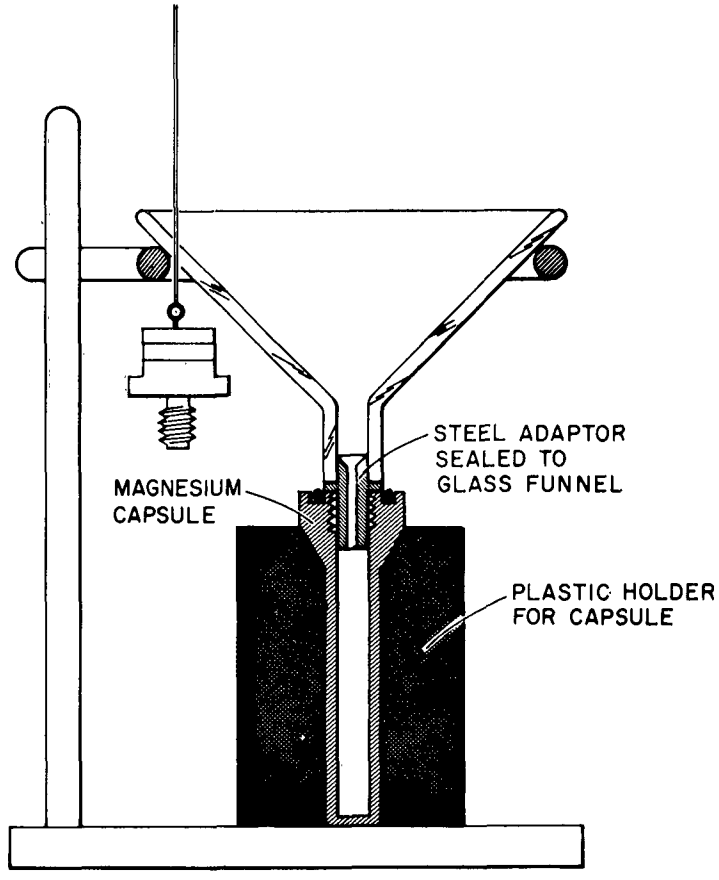


Fig. 2 Capsule Filling

The radioactive capsule was positioned in front of the access hole and a reading on a T1B survey meter was obtained at a fixed distance of 31 in. to estimate the curie content.

A shipping container was covered with polyethylene and sent into the cell with the monorail crane. Its lid was removed with a jib crane. The radioactive capsule was inserted in the container, and the plastic bag containing the string was allowed to hang on the outside. There was adequate clearance between the container wall and the lid to avoid cutting the string when the lid was carefully lowered into place. The container was removed from the hot cell and the contaminated plastic covering was replaced with clean polyethylene.

Preparation of Calibration Sources

Calibration sources of La^{140} consisting of accurately measured aliquots of the same solution were prepared. The activity levels were selected so that the weaker sources could be counted in the large area scintillation counter, and the stronger source could be measured with a Victoreen condenser r-meter thus providing experimental correlation of the two radiation measurements. Every effort was made to eliminate processing and transfer losses so that the dilution factor would be equal to the activity ratio of the sources.

Three calibration sources were prepared for shipment to the NTS along with the magnesium capsule on 17 November. One hundred microliters of the active La^{140} solution A was diluted to make 100 ml of solution B. The first calibration source consisted of 100 microliters of solution B, which was pipetted on tissue paper, dried, and securely packaged in a plastic box. The second calibration source was prepared in a similar manner using 1 ml of solution B. The first and second sources were measured in the $4\text{-}\pi$ ionization chamber. The third calibration source was prepared by pipetting 4.85 ml of solution A into an aluminum capsule with the same dimensions as the magnesium capsules. The aluminum capsule was placed under a heat lamp and the contents carefully evaporated to dryness. The lid was then pressed in place and secured by crimping the capsule top. A 30-ft string was attached so that the aluminum capsule could be handled at the NTS with the same equipment that was used for the magnesium capsules.

Another pair of similarly prepared calibration sources were sent with the 24 November shipment to the NTS. One source was 0.1 microliter and the other was 5 ml of the same solution, prepared and packaged as described above. The 0.1-microliter source was measured in the $4\text{-}\pi$ ionization chamber, and the 5-ml source was measured with a

Victoreen condensor 4-meter at Camp Parks. The magnesium capsule for this shipment was also measured with the condensor r-meter at Camp Parks.

For row charges involving 5 capsules, 3 capsules were placed in one shipping container and 2 capsules were placed in the other.

The package(s) was placed on an AEC truck for shipment to NTS.

SOME STUDIES ON DEBRIS FROM THE THIRD ROW CHARGE

Mass and Activity Distribution by Particle Size

Several hundred grams of debris from the detonation of the third row charge were sent to Camp Parks. The sample was oven-dried and quartered to obtain a representative fraction for dry sieving. One hundred grams was Ro-tapped for 10 min through a nest of Tyler sieves. Fractions from the 6, 14, 48, 80, 170, 325 mesh sieves and the pan fraction were weighed and the gamma activity measured in a well-crystal scintillation counter.

A second 100-gram portion was wet sieved through a 325-mesh screen. The material remaining on the screen was dried and Ro-tapped as described above for the dry sieving. Material passing the 325-mesh screen was transferred to a glass cylinder with a thermally insulated vacuum jacket containing a volume of water adjusted to 2000 ml. The cylinder was shaken to uniformly disperse the sample and then set in an upright position. As the soil particles settled through the vertical column of water, 10 ml aliquots were removed from a depth of 10 cm below the original liquid level. Successive aliquots were taken in previously weighed 10-ml volumetric flasks at times which excluded 30, 18, 9, 5, and 1-micron particles. The flasks were centrifuged and the supernate withdrawn. They were then oven-dried to constant weight and their gamma activity measured in a well-crystal scintillation counter.

Leaching of La^{140}

The leaching of La^{140} from soil particles by 0.1 N HCl solution, distilled water, natural seawater, and 0.1 N NaOH solution was determined. A duplicate set of test tubes containing 25 ml of each of the above solutions were sent to NTS. After the third row charge was detonated on 30 January, 5 grams of the resulting debris was placed in each of the centrifuge tubes by NCG personnel. The tubes and contents were

returned to Camp Parks. On 5 February the tubes were centrifuged, the liquid decanted into clean tubes, and the La^{140} of the solid and liquid fractions measured in the well-crystal scintillation counter.

Exchange of La^{140} to Clay and Loam

The desorption of La^{140} from soil and its readsorption on montmorillinite clay and adobe soil was also studied. Adobe soil from Camp Parks, and commercial clay from Industrial Mineral and Chemical Co., Florin, Calif. were passed through a 325-mesh sieve to obtain particles less than 44 micron in diameter. A set of test tubes, each in duplicate, containing 5 grams of adobe or clay plus 25 ml distilled water, were prepared and sent to the NTS.

Debris from the third row charge was sieved through a 100-mesh screen to obtain particles larger than 149 micron in diameter. Five grams of the material retained on the 100-mesh screen was added to each of the test tubes on 30 January. The tubes were returned to Camp Parks. On 5 February the debris was separated from the clay and adobe by washing through a 325-mesh sieve. The gamma activity of the fractions was measured in a well-crystal scintillation counter.

RESULTS AND DISCUSSION

A total of 29 radioactive capsules were prepared instead of the 21 originally planned. Three additional single charges and one additional row charge were necessary to meet the objectives of the pre-Buggy experiment. Despite delays and schedule revisions the capsules were prepared and delivered as required.

Table 1 shows the estimated activity of the single-charge capsules and Table 2 shows the estimated activity of the capsules for row charges. The estimates are based on TlB survey instrument measurements, except capsule 3, 4, and 5 which were measured with a Victoreen condenser r-meter. In all cases the capsules contained the proper amount of activity to provide a satisfactory radiotracer on the debris. The capsules for each row charge contained an almost identical amount of activity.

Table 3 gives the calibration source measurements which were made at Camp Parks. These sources were again measured at NTS with a Victoreen condenser r-meter, and a large-area-scintillation counter. In this manner the scintillation count rate was converted directly to fraction

TABLE 1

T1B Estimate of Capsule Activity

Single Charge Number	Capsule	Date	Time	r/hr at 31 in.	Curies (est.)
1	1	10 Nov	2000	28	65
2	2	17 Nov	1800	17	39
3	3	24 Nov	1500	22	50.2*
1	4	4 Dec	1800	9	21.5*
2	5	8 Dec	1600	13	30.3*
3	6	8 Dec	1700	30	70
4	7	11 Dec	2400	24	56
5	8	16 Dec	1200	10	23
6	9	16 Dec	1300	16	38

*Values measured with Victoreen condenser r-meter at Camp Parks, using the conversion factor 1 curie = 1.2 r/hr at 1 meter.

TABLE 2

T1B Estimate of Capsule Activity

Row Charge Number	Capsule	Date	Time	r/hr at 31 in.	Curies (est)
1	10	13 Jan	1630	8.5	20
	11		1635	8.5	20
	12		1700	8.5	20
	13		1730	7.8	18
	14		1730	7.8	18
2	15	20 Jan	1400	9	21
	16			9	21
	17			9	21
	18			9	21
	19			9	21
3	20	27 Jan	1600	12	28
	21			10	23
	22			9	21
	23			10	23
	24			10	23
4	25	5 Feb	1000	12	28
	26			12	28
	27			12	28
	28			12	28
	29			12	28

TABLE 3

Calibration Source Measurements at Camp Parks

Source	Date	Time	La^{140} Activity	Activity Ratio
1	17 Nov	1500	19.4 μc*	$\frac{\text{Source 3}}{\text{Source 1}} = 4.85 \times 10^4$
2	17 Nov	1500	189 μc*	$\frac{\text{Source 2}}{\text{Source 1}} = 10$
3	17 Nov	1500	-	$\frac{\text{Source 3}}{\text{Source 2}} = 4.85 \times 10^3$
4	24 Nov	1540	26.8 μc*	$\frac{\text{Source 5}}{\text{Source 4}} = 5 \times 10^4$
5	24 Nov	1540	1.33 c**	

* Measurement made with 4-pi ionization chamber.
**Measurement made with Victoreen condenser r-meter.

of total activity, independent of the curie assay. The Nuclear Cratering Group reported the following values for the 17 November and 24 November calibration sources:

$$17 \text{ Nov } \frac{\text{c/m}}{\text{r/hr at 1 m}} = 3.06 \times 10^8$$

$$24 \text{ Nov } \frac{\text{c/m}}{\text{r/hr at 1 m}} = 2.9 \times 10^8$$

The good agreement between the two values indicates a low experimental error.

The decay measurements which were made on each batch of La^{140} showed that in all cases the Ba-La separation was better than 98 %. Ba^{140} and La^{140} were the only radionuclides which could be identified in the pulse height spectra after the La^{140} had decayed through seven half-lives.

The particle size distribution and activity distribution data from wet sieving are presented in Table 4, and they are plotted as cumulative percent of total in Fig. 3. The particle size distribution and activity distribution data from dry sieving are presented in Table 5, and are plotted as cumulative percent of total in Fig. 4. The increase of both activity and mass in small particles by wet sieving indicates that small particles adhered to large particles in the dry sieving analysis.

The dry sieve data may be the best measure of rate of particle deposition, if it is assumed that the agglomerates existed at the time in question, because the falling rate would be controlled by the agglomerated particles. However, the mechanism by which the radionuclides become attached to the soil particles is better described by the wet sieve results. No spherical, glassy particles which are typical of melted debris were observed in the sample from the 3rd row charge. Therefore, it would be expected that the radionuclides would be adsorbed on the surface of the particles. The cumulative percent of surface area was plotted in Fig. 3, and shows an excellent fit with the activity distribution curve.

Analysis of debris from the nuclear detonation at Sedan indicated that the gamma activity was proportional to the mass or volume of particles; i.e., the specific activity was approximately constant for all particle sizes.[1] A typical result obtained on Sedan debris is shown in Fig. 5.

Thus, an extrapolation of uncorrected data of vented radioactivity found at pre-Buggy, to the expected data from a nuclear detonation such as Sedan would tend to give a high result.

The leaching results in Table 6 show that the La^{140} was removed from the debris by acid solution and was undisturbed by basic and neutral solution. The results are consistent with the solution chemistry of lanthanum. The results also indicate that the use of water causes no error in the liquid sedimentation method for sub-sieve analysis.

The exchange data in Table 7 show that La^{140} did exchange from the debris to particles with a higher adsorptive capacity. The commercial clay has a higher catonic adsorptive capacity than the adobe soil and consequently removed a larger fraction of the La^{140}. These results are similar to those found for debris from Sedan.

TABLE 4

Wet Sieve Analysis of Debris From 3rd Row Charge

Sieve Analysis (100 g Sample) Mesh	Microns Diameter	Grams Retained	Activity (c/m)	Cumulative Mass (% of Total)	Cumulative Activity (% of Total)	Cumulative Surface Area* (% of Total)
6	3360	8.63	19,700	91.37	99.8	100
14	1190	21.55	33,400	69.82	99.5	99.9
48	295	35.12	66,300	34.70	99.2	98.8
80	175	11.93	36,100	22.77	98.5	95.8
170	88	10.78	145,000	11.99	98.0	92.8
325	44	4.01	430,000	7.98	96.0	90.5
Sub-Sieve Analysis						
Micron Diameter	grams/10 ml					
30	0.0275		32,400	5.55	90.0	87.7
18	0.0267		28,200	5.35	78.0	87.4
9	0.0214		lost	4.29		84.2
5	0.0167		lost	3.34		79.0
1	0.0059		21,300	1.18	59.0	58.0

*Surface area was calculated assuming that all particles were spheres with the diameter which is listed in the data. Thus 1.18 % of the mass was assumed to have a particle diameter of 1 micron.

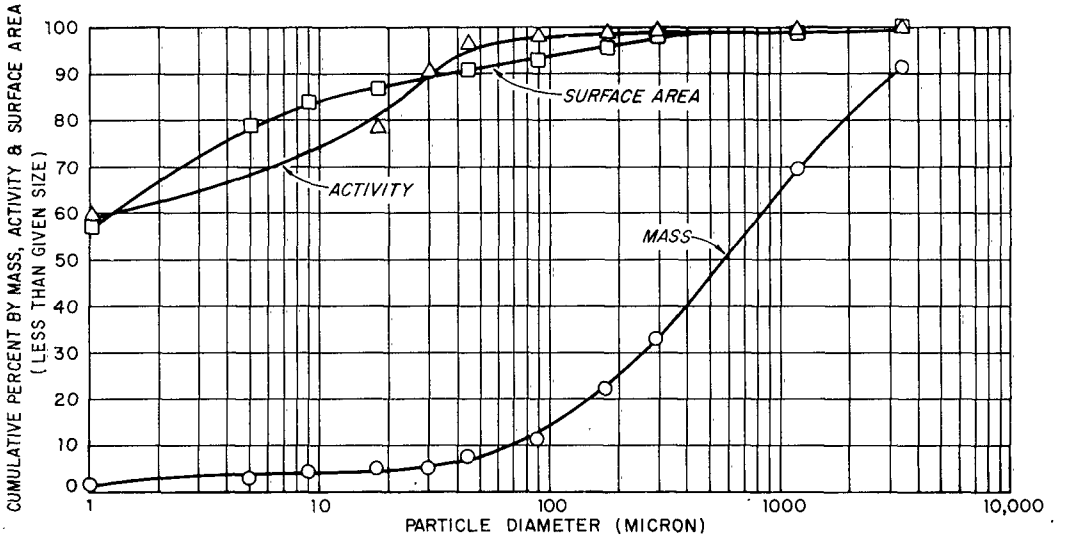


Fig. 3 Wet Sieve Analysis

TABLE 5

Dry Sieve Analysis of Debris From 3rd Row Charge

Mesh	Micron Diameter	Grams Retained	Activity (c/m)	Cumulative Mass (% of total)	Cumulative Activity (% of total)
6	3360	12.97	10,000	85.77	99.4
14	1190	24.04	55,000	61.73	95.8
48	295	34.97	232,000	26.76	81.7
80	175	12.37	112,000	14.39	73.9
170	88	9.16	123,000	9.16	66.2
325	44	3.11	294,000	2.12	47.4
Pan	< 44	2.12	744,000		

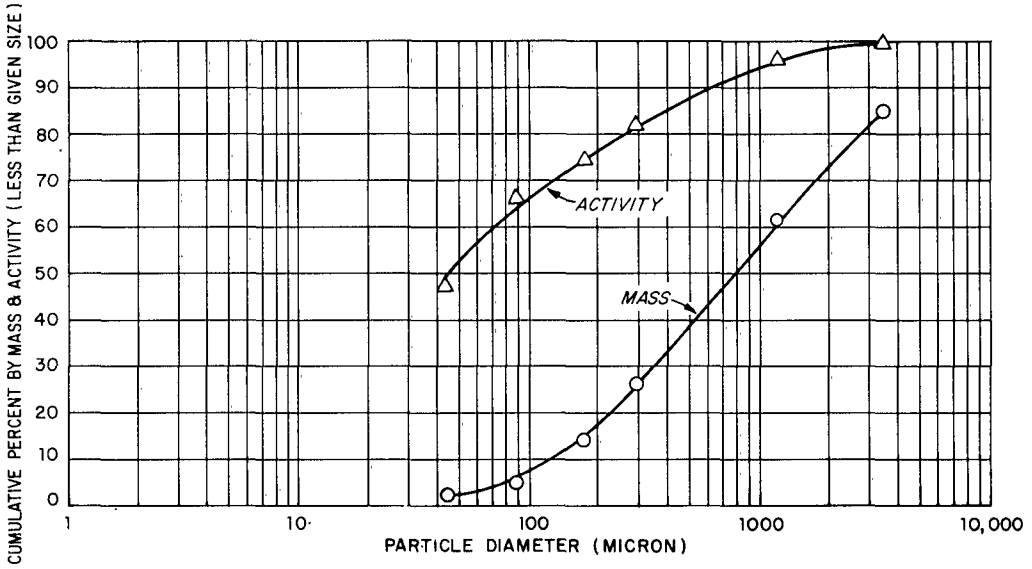


Fig. 4 Dry Sieve Analysis

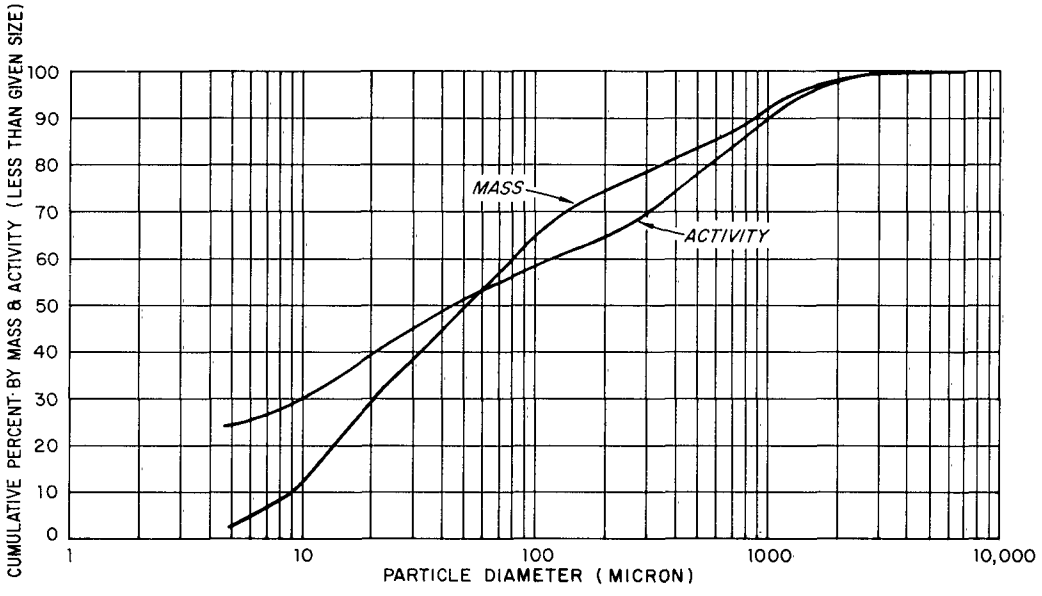


Fig. 5 Sedan Particle Analysis by Wet Sieve

TABLE 6

Leaching of La^{140} From Debris by Solutions

Solution	25 ml Solution (c/m)	5 Grams Debris (c/m)	% Leached
0.1 N-HCl	79700	199400	40.0
	62100	113100	35.5
Water	525	206300	0.25
	415	229700	0.18
Seawater	2670	202400	1.32
	1660	224100	0.74
0.1 N-NaOH	316	187100	0.17
	319	224200	0.14

TABLE 7

Exchange of La^{140} From Debris to Clay or to Adobe

	5 g Clay or Adobe (c/m)	5 g Debris (c/m)	% Exchanged
Adobe	102900	47900	68.3
	lost		
Clay	133000	27800	82.7
	140500	20000	87.6

CONCLUSIONS

1. Capsules were prepared and delivered as required by the pre-Buggy test schedule.

2. The capsules contained the proper amount of La^{140}.

3. Precise sources made possible the calibration of a large-area scintillation counter in units measured by the Victoreen condenser r-meter.

4. The La^{140} was distributed on the particles as a function of surface area; 90 % of the activity was on sub-sieve (< 44 micron) particles which comprised only 8 % of the mass.

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1	Allis-Chalmers Manufacturing Co., Washington
1	Allison Division - GMC
2	Argonne Cancer Research Hospital
10	Argonne National Laboratory
1	Atomic Bomb Casualty Commission
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1	AEC Scientific Representative, Japan
3	Atomic Energy Commission, Washington
4	Atomic Energy of Canada, Limited
4	Atomics International
2	Babcock and Wilcox Company
2	Battelle Memorial Institute
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1	Borden Chemical Company
4	Brookhaven National Laboratory
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1	Bureau of Mines, Salt Lake City
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1	Chicago Patent Group
1	Columbia University (Cropper)
1	Combustion Engineering, Inc.
1	Combustion Engineering, Inc. (NRD)
1	Committee on the Effects of Atomic Radiation
1	Defence Research Member
1	Denver Research Institute
1	Division of Raw Materials, Washington
1	Dow Chemical Company, Rocky Flats
3	duPont Company, Aiken
1	duPont Company, Wilmington
1	Edgerton, Germeshausen and Grier, Inc., Goleta
1	Edgerton, Germeshausen and Grier, Inc., Las Vegas
1	Fundamental Methods Association
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2	General Dynamics, Fort Worth
2	General Electric Company, Cincinnati
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1	General Electric Company, San Jose
1	General Electric Company, St. Petersburg
1	General Scientific Corporation

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1	Grand Junction Office
1	Hughes Aircraft Company, Culver City
1	Iowa State University
1	Jet Propulsion Laboratory
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2	Los Alamos Scientific Laboratory (Library)
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1	Maritime Administration
1	Martin-Marietta Corporation
1	Massachusetts Institute of Technology
1	Monsanto Chemical Company
1	Mount Laboratory
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2	NASA, Scientific and Technical Information Facility
1	National Bureau of Standards (Library)
1	National Bureau of Standards (Taylor)
1	National Lead Company of Ohio
1	New Brunswick Area Office
1	New York Operations Office
1	Nuclear Materials and Equipment Corporation
1	Nuclear Metals, Inc.
1	Office of Assistant General Counsel for Patents
4	Phillips Petroleum Company
1	Power Reactor Development Company
4	Pratt and Whitney Aircraft Division
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2	Public Health Service, Washington
1	Public Health Service, Las Vegas
1	Public Health Service, Montgomery
1	Purdue University
1	Radiation Applications, Inc.
1	Sandia Corporation, Albuquerque
1	Sandia Corporation, Livermore
1	Technical Research Group
1	Tracerlab, Inc., Richmond
3	Union Carbide Nuclear Company (ORGDP)
4	Union Carbide Nuclear Company (ORNL)
1	Union Carbide Nuclear Company (Paducah Plant)
1	United Nuclear Corporation (NDA)
1	U. S. Geological Survey, Denver
1	U. S. Geological Survey, Menlo Park
1	U. S. Geological Survey, Naval Weapons Plant
1	U. S. Geological Survey, Washington
1	U. S. Geological Survey, WR Division

2	University of California Lawrence Radiation Lab., Berkeley
2	University of California Lawrence Radiation Lab., Livermore
1	University of California, Los Angeles
1	University of Hawaii
1	University of Puerto Rico
1	University of Rochester (Atomic Energy Project)
1	University of Utah
1	University of Washington (Donaldson)
2	Westinghouse Bettis Atomic Power Laboratory
1	Westinghouse Electric Corporation (Rahilly)
1	Westinghouse Electric Corporation (NASA)
1	Yankee Atomic Electric Company
25	Technical Information Extension, Oak Ridge

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NRDL assisted in this experiment by preparing 29 capsules containing curie amounts of La^{140} for shipment to the Nevada Test Site (NTS) on schedule. The level of gamma activity in each capsule was sufficient to provide a radiotracing of the debris which resulted from the detonation.

In addition NRDL furnished "always open" fallout collectors to sample the debris, and a low-geometry scintillation counter to measure its La^{140} content.

Particle size measurements of the debris indicated that La^{140} was adsorbed on the surface of the soil particles. Some 96% of the activity was associated with sub-sieve particles representing only 8% of the mass and 90% of the available surface area.

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